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SCALE MODEL OF THE SUEZ CANAL

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SCALE MODEL OF THE SUEZ CANAL

Paul Blanquet[1]

PRELIMINARY

We all know how widespread scale-model experimentation in connection with hydraulic projects has become in recent years. Regulating systems for river basins, hydroelectric installations, coastal defenses, ocean and inland harbor works, are today executed only after their design has first met the test of laboratory experiment.

The Universal Suez Canal Company, being perennially concerned to improve the great world highway in its charge as the best interests of the traffic may dictate, has also lately begun to turn to experimentation for guidance in its projects.

In particular, these experiments have been intended primarily to ascertain the manner of variation of hydraulic phenomena due to passage of shipping as functions of the reciprocal features of the Canal and its traffic, and conversely, the effects of such phenomena on the channel and banks of the Canal.

It may be recalled that the Suez Canal, which on the whole follows a straight line, was cut through generally loose soil; its trapezoidal section is now dredged to 46 feet below low water, with underwater slopes varying from 3:1 to 4:1 (base to height); and berms 15 to 50 feet in width, under 3 to 13 feet of water, are provided along the sides. The banks, which are stripped of vegetation, are lined with pavings of various types, which are referred to by the generic name of "facings." The transverse section is defined by a width of 197 feet measured at a depth of 36 feet under low water. The water surface between facings is thus about 500 feet across on the average.

Now it is known that any vessel passing through the comparatively narrow section of a canal, owing both to the suction behind it due to its progress and to the flow of water astern produced by the screws, sets up strong lateral countercurrents with depression of water level, followed by one or more elevated crests, frequently breaking up into vortexes and eddies. Over the berms, which are not very far under water (3 to 6 feet), the depression of level is often further attended by a spill current which is added to the countercurrent proper and tends to expose the berms. This spill current, which is directed obliquely to the centerline of the canal, is even faster than the countercurrent itself, and hence exerts a considerable erosive action.

These hydraulic phenomena, then, especially if of marked degree, bring about a removal of underwater material from the berms of the canal, and this material accumulates in the bottom of the channel, diminishing its depth, while at the same time literally undermining the paving on the banks. Thus we can see the doubly injurious consequences of this effect, which recurs with every passage of a vessel, both with respect to maintenance of the dredged bottom and with respect to preservation of the stability of the banks; and the effect has intensified with progressive advance in size and number of ships

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using the canal, and especially with their increasing speed, mandatory in view of the growing volume of traffic handled.

Before adopting remedial measures in this situation, it was of course necessary for the Canal Company to study their potentialities in terms of the various parameters involved, and for this purpose scale-model experimentation was highly indicated. Of course, laboratory tests were preceded by a program of observations and measurements on the Canal itself, to serve as an aid in the experiments. Conclusions drawn from the laboratory work will in turn be subjected to verification by full-scale execution, at various points along the canal, of such modifications in the form and dimensions of the channel as the experiments suggest; unquestionably, however, only the use of a scale model could have made numerous experiments possible within a limited time, and the conclusions from these experiments, some of which could not otherwise have been performed at all, will prove an invaluable guide in projected improvements of the Canal.

Organization of Tests

A number of hydraulics laboratories of high scientific standing are today specializing in research of this kind, though none, so far as we know, had yet attacked just this specific problem of erosion in a maritime canal. Among such laboratories, we had had the privilege of inspecting and admiring the Corps of Engineers' magnificent Vicksburg Experiment Station; and all European hydraulic engineers are similarly familiar, at least by reputation, with the Bureau of Reclamation's celebrated hydraulics laboratory at Denver, Colorado.

For the scale-model testing on our Canal, we turned to the Société NEYRPIC's Laboratoire Dauphinois d'Hydraulique at Grenoble, in France. American engineers will recall the study of the Rhine waterway assigned to that laboratory by the U. S. VIth Army Group Command, and the fruitfulness of that project. Since that time, often in collaboration with American colleagues, the research workers at Grenoble have greatly extended the scope of their inquiries, and they approached our difficult problem with keen interest, in close cooperation, of course, with engineers of the Suez Canal Company.

Our problem was difficult in many aspects. In the first place, the Isthmus of Suez consists of widely various soils, ranging from very soft mud to hard plates of gypsum and limestone. It was obviously impossible to reproduce this variety of soils in a model. We accordingly did not ask the Laboratory to attack the problem of effects of a hydraulic phenomenon on various kinds of substrate, but rather that of variation of such effects upon a single given material as a function of speed of vessel and the several geometrical features of the Canal. Nor were any of the materials of the Canal itself eligible for use, not only for reasons of distance but because of the excessive cohesion of the natural substrates, which would have led to far too gradual rates of change in the model. After some trials, the Laboratory selected a Drôme River sand which, at the pitch of 4:1 adopted for the slopes, proved sufficiently stable while yet sufficiently sensitive to repeated transit of the ship model.

A second difficulty arose from the variety of types and sizes of vessels passing through the Suez Canal. Here again, it was necessary in practice to choose a single prototype for the laboratory ship model, and this was felt to be sufficient provided the hydraulic effect produced was at least equal to the most marked effects encountered in actuality. The prototype actually selected was a large American oil tanker that makes frequent passages through the

Suez Canal, the Sovac Comet of 31,000 tons gross burden, single screw, commissioned 1950, belonging to the Socony Vacuum Oil Co. The ship model, which was self-propelled and rudderless but constrained to travel down the center of the canal, was to make 50 successive passages in one direction and then 50 in the other direction, and so forth, until the resulting erosion had reached the maximum.

A third difficulty in the project consisted in that the hydraulic phenomena and their underwater erosion effects that were to be reproduced and measured, despite their absolute extent, are small relative to the size of the Canal. Since moreover any distortion was undesirable in a physical problem of this kind, it was necessary to choose a sufficiently large scale to permit measurement, while avoiding unreasonably large size of works and ship model. The scale adopted was 1:25.

Such were the basic conditions of the test project.

Description of Model and Accessories

The model is contained in a concrete trough 210 feet in length, flanked by two parallel straight walls 29-1/2 feet apart and 5 feet in height.

At each end, the trough opens into a circular basin 37 feet in diameter, in which the ship model can be turned end-for-end. Concentrically with the walls enclosing these basins, on the inside, there is an additional wall 3 feet high and surmounted by carefully leveled structural steel members, to serve as an overflow.

Water from the model overflows continuously into the gap between these inside and outside walls of the end basins, and is returned to the model by a pump through perforated pipes located at the junctions between the basins and the canal proper. This arrangement absorbs the waves set up by the movements of the ship model. When the model is filled with water and the end pumps are in operation, the surface stabilizes itself at a level which can be read by sighting on two "gage chambers" installed at each end of the model. The current set up by the pumps themselves is practically negligible in the central portion of the canal, and has no effect whatever on the behavior of bottom materials.

The Sovac Comet model has a hull about 26 feet in length. Its screw observes similitude in diameter and in pitch with that of the actual vessel; however, it has been necessary to modify the shape slightly and increase the thickness somewhat to permit construction in practice. Nevertheless, it has been verified that the thrust of the model screw duly corresponds to that of one strictly similar in shape to the prototype. An electric motor powered by batteries carried on board the ship model drives the screw. In addition, the ship model is accompanied in its passage by a traveling bridge running at the same speed as itself upon rails mounted on the walls of the canal. The function of this bridge is threefold. It keeps the ship model in the middle of the canal; it lends it an additional thrust of about 20 pounds serving to overcome the difference in friction drag between model and prototype; and it carries the operator, the controls, and the speed-recording instruments. Like the ship model, the bridge is driven by an electric motor and storage batteries; a rheostat serves for speed control.

The central portion of the canal is lined with sand throughout the width and over a length of 130 feet. This sand is modeled to the profile of the actual Canal by means of a scraper template attached to another movable bridge, called the modeling bridge. This bridge, also driven by an electric motor, normally remains at one end of the model.

A third bridge, normally stationed at the other end of the model, serves for periodic checking of transverse sections. For this purpose, it bears a carriage equipped with an electric-field sounder mounted on a vertical rod which plunges into the water at a constant speed. When the sounder approaches the bottom, it is stopped at an adjustable distance from it. The position of stoppage, immediately after which the sounder reascends, is marked on the tape of a Crouzet recorder. At the same time, a metal point attached alongside the sounder serves to detect the water level. Finally, the position of the carriage, which moves at low constant speed on the bridge, is recorded by means of space indexes. The recording thus takes the form of dots more or less widely spaced according to the depth of the sounding, and indicating the bottom and the water level. The depth as recorded is 1/5 of the depths in the model. These soundings are taken every 50 trips of the ship model, and analyzed by planimetry.

To measure the countercurrents, two Dumas logs were first used, attached to the ship model itself on the port side, one amidships and one astern. The speed of the ship model being constant and the section of the canal uniform, the countercurrent was a stationary phenomenon relative to the vessel, and thus readily measured. In practice, however, precision proved unsatisfactory, inasmuch as the velocities recorded varied with the point of attachment to the ship model and failed to indicate the required maximum speed. This arrangement was therefore soon replaced with a Beauvert type microlog, which is installed on a fixed arm imbedded in one of the walls of the model and transmits its indications, in the form of variations in an electric field, to a cathode oscillator. This latter procedure proved entirely satisfactory.

To measure depression of water level, a NEYRPIC type wave recorder was used. This consists substantially of a "grill" of vertical insulated conductive wires immersed halfway in the water, with which they accordingly form a condenser of capacitance varying with the water level. This variation in capacitance, detected and amplified by an electronic circuit, is recorded on the tape of a Pekly recorder. Prior calibration serves to establish the relationship between the variation in level and the indications of the recorder. Not only the depression of water surface but also the speed of the waves following it is thus precisely known.

In addition to the effect of these hydraulic phenomena on the bottom of the canal, they are known likewise to affect the equilibrium of the vessel, which digs itself further into the water ("squatting"). As in fullscale observations taken on the Canal, this squatting was measured in the laboratory by telescope readings from the bank on a self-reading rod set up on the ship model.

The effects of movements of water on the paving of the banks, on the other hand, were not to be studied in the model, far more instructive data having already been accumulated at the Canal than could have been gained from small-scale experiments. Likewise, the facings were nearly simulated by waterproof plates deeply set in the sand of the banks. The only parameter of the facings that was to be investigated for possible effect on changes in the berms was their shape. In particular, five different shapes corresponding to the chief types employed on the Canal were tested at the Laboratory: entirely vertical wall, single-slope 3:2 wall, single-slope 3:1 wall, vertical wall followed by 3:2 incline, vertical wall followed by 5:1 step and 1:1 facing.

Similitude of Phenomena

The similarity employed in the laboratory tests was that of Froude's law. Linear dimensions were reduced in a proportion of 1/25, and the time and

velocity scale was 1/5. The speed of the screw, on the other hand, is multiplied by 5. Owing to the aforesaid expedient of applying extra thrust through the bridge guiding the ship model, the hydraulic flux set up by the screw in the model is in similitude with the corresponding phenomenon in the actual Canal.

Under these conditions, it was estimated from verification experiments on the model that similitude of hydraulic phenomena was achieved at least within 5%.

On the other hand, similitude of transport of materials presented more difficult problems. As has been explained, the sand used in the tests could not be expected to behave, at scale velocities, exactly like the actual materials, not being of the same mobility, cohesion, or penetrability. Nor was such similarity essential. It was sufficient that the section of the canal model should successively assume shapes geometrically similar to the successive shapes of the prototype, so as to provide an "over-all similarity" of effects regardless of the time required to produce them.

Similarity of erosion, in this sense, judging from the comparative experiments initially performed, may be regarded as qualitatively achieved in the tests. The quantitative situation will be considered below.

Tests Performed

The tests performed, which covered the period of one year from June 1952 to June 1953 and totaled more than 4000 trips of the ship model, may be divided into three successive phases.

The first phase, covering one month, involved a break-in period and verification of similarity between the model and the prototype. The channel section was graded to 44-foot depth below mean level and the slopes to 4:1, leaving two symmetrical berms, each 33 feet in width, for a wetted area of 1455 square yards between the vertical wall facings. The ship model, ballasted to 31' at rest, made 450 trips at 8 nautical miles per hour. The phenomena observed under these conditions duly corresponded to those that had been found on the Canal, and this verification accordingly warranted going on to the experiments proper.

In the second phase, covering eight months and nearly 2200 trips, tests performed on the same wetted area of 1455 square yards initially, but with the draft of the ship model changed first to 34' (at rest) and then to 36', served to investigate:

1. Progress of erosion at the foot of the five different types of facings, as a function of number of trips;
2. Variation of hydraulic phenomena with speed of vessel;
3. For equal section, the effect of shape of section on hydraulic phenomena and on erosion at foot of facings;
4. Velocity of countercurrent under the hull of the vessel.

In the third and last phase, covering three months and nearly 1600 trips, tests performed at a uniform draft of 34' on the ship model, but with an initial wetted area of about 1670 and then 1550 square yards on the channel, served to investigate:

1. Progress of hydraulic phenomena and attendant erosion as a function of size of wetted area;
2. Variation in hydraulic phenomena and erosion upon increase in speed of vessel, for given size and shape of section;

3. Effect of shape of section on the various phenomena involved, for a given size of such section.

Finally, independently of the model, special tests were performed in a closed pipe with sight glass to compare the sand used in the experiments with actual material from the Canal, taken from the point selected for the verifying observations. The two materials were thus successively subjected first to the action of a uniform flow and then to that of a breaking wave in order to evaluate their comparative reactions to erosive forces and estimate to what extent the experimental findings on erosion were transferable to actuality.

Results of Tests

The results obtained are of three kinds:

- Effect of parameters involved on depression of water surface, velocity of countercurrent and squatting of vessel;
- Effect of these parameters on transport of materials in the model;
- Transfer of these findings to actuality.

In the following account of these results, the data have been converted to full scale for convenience.

Hydraulic Phenomena and Squatting of Vessel

a) Effect of speed of vessel

This effect is considerable for all variables. Thus for an equal area of 1555 square yards, when the speed of the vessel is increased from 8 to 8-1/2 nautical miles per hour:

- The maximum velocity of countercurrent is changed from 7-1/2 to 9-1/2 feet per second;
- The maximum depression of water surface is changed from 4-1/2 to 5-1/2 feet;
- Squat of vessel (astern) is changed from 3 to 5 feet.

In other words, an increase of 7% in speed increases the countercurrent by 29%, the depression of surface by 26% and the squat by 45%.

b) Effect of area of wetted surface

This effect is likewise very pronounced. Thus an increase in surface area by 7% reduces the other variables in question by around 20%.

c) Effect of draft of vessel

While this effect was not investigated systematically, it emerges clearly from the following measurements:

Draft	Maximum Depression	Countercurrent
31 feet	5 feet	7-1/2 feet
34	5-1/2	8 to 9
36	6-1/2	12-1/2
	(for speed of 8 nautical miles/hour)	(for speed of 8-1/4 nautical miles/hour)

d) Effect of shape of section

This effect has not been satisfactorily quantified, but it is definitely

significant, especially with respect to the velocity of the countercurrent. It may be said that for equal area, a form of channel more removed from the hull of the vessel, i.e. with lower, wider and steeper-walled bottom, reduces the values of hydraulic variables.

Transport of Materials in the Model

The findings are as follows:

a) The slopes do not change much, the filling of the bottom closely paralleling the erosion of the berms.

b) As the berms erode, they remain substantially horizontal down to a limiting position.

c) The shapes of facings tested do not appear to have any effect on the rate of erosion or on its limiting extent.

d) On the other hand, the speed of the vessel has a considerable effect on the rate and ultimate extent of erosion. For example, for an area of 1555 square yards, the limiting depth established itself at 6 feet for a vessel speed of 8 nautical miles and at 9 feet for a speed of 8-1/2 nautical miles per hour.

e) Likewise, the area of the wetted surface has a powerful effect on erosion. Thus for a vessel speed of 8 nautical miles per hour, the limiting depth is 10 feet at an area of 1435 square yards and 6 feet at an area of 1550 square yards, while for an area of 1670 square yards, the berm remains at its initial depth of 3-1/4 feet.

f) The shape of the section also affects erosion of the berms, which behave more satisfactorily, for like section area, when the shape is such as to clear the hull of the vessel amply. In that case the countercurrent is found to be stronger under the hull and at the bottom of the channel, thus reducing its value at the top near the berms.

Transfer of Erosion Findings to Actuality

Comparative testing of the Canal and model materials yielded the following findings:

a) The critical velocity of transport of Canal mud by a current of water decreases sharply as the water content of the mud increases. For the average water content found at the time of sampling, the critical velocity is 7 feet per second, whereas the critical velocity of the model sand, or 9 inches per second, would correspond to an actual velocity of 4 feet per second.

The Canal material is thus less sensitive than the model material to transport by a current of water.

b) The possibility of erosion due to breaking of waves increases considerably with the water content of the Canal mud. Such erosion, inappreciable for a water content of 43%, becomes very rapid for a water content of 50%. The typical Canal material appears to be more sensitive to this breaking effect than the model sand.

Therefore, as regards the action of the countercurrent, there must be a margin of safety in transfer of the model results to actuality. Substantially, the contrary is the case with respect to vortex action. On the other hand, it is to be presumed that such vortex action diminishes considerably with increasing depth of water over the berms, and that it becomes negligible,

relative to the effect of the countercurrent, when the berms are much eroded.

Subject to the reservations to be borne in mind as regards the validity of these comparisons, in view of the actual water content and variety of the Canal materials, it is thus to be concluded that in actuality, an equilibrium elevation is to be expected on the berms. As for the quantitative prediction of this elevation, it seems likely that the elevations found in the model, when converted to full scale, are on the safe side when only the countercurrent is operating, as is so on small sections providing a very low berm limit. For large sections providing a comparatively high berm limit, however, transfer to actuality may tend to yield over-optimistic results because of persistent vortex action.

CONCLUSIONS

Summarizing, tests performed over a period of one year on a scale model of the Suez Canal have led to the following conclusions:

1. Shape of facings does not appear to have any appreciable effect on berm erosion.

2. For wetted areas from 1430 to 1550 square yards, deepening of bottom (to - 50-1/2 feet) appreciably reduces berm erosion.

3. For sections of this general size, the effect of speed of the vessel on erosion phenomena, like that of wetted area, is considerable.

4. It is of importance both to adopt a shape of channel clearing the hulls of vessels as amply as possible and to make the berms of adequate width to maintain stability of the facings.

5. Similar transfer of the limit erosions found in the tests to actuality may be regarded as valid, at least under the assumptions stated.

Despite the reservations to which the foregoing conclusions are rendered subject by the assumptions mentioned, the results obtained are certain to prove a valuable guide in the solution of engineering problems on the Suez Canal.

PROCEEDINGS-SEPARATES

The technical papers published in the past year are presented below. Technical-division sponsorship is indicated by an abbreviation at the end of each Separate Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

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c. Discussion of several papers, grouped by Divisions.
d. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.
e. Presented at the Atlantic City (N.J.) Convention in June, 1954.

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